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APPLICATION OF MODEL-BASED REASONING TOOLS USED TO ENHANCE AND IMPROVE DIAGNOSTIC PERFORMANCE TO IMPROVE AIR FORCE MAINTENANCE

Giordano Automation Corp.

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Under this contract initiatives were conducted to improve the sustainment and modernization of the Turbine Engine Monitoring System (TEMS). TEMS is deployed on the A-10 and KC-135 aircraft to monitor engine parameters and provide alerts to ground crew upon the occurrence of Malfunction Transactions (MALTRAN). The TEMS system was designed around 1970's technology, and has numerous sustainment issues because of aging and diminishing manufacturing source (DMS) issues. This program was conducted under a Program Research and Development (PRDA) effort. The efforts represent a true partnership between the two sides of the Air Force that rarely communicate: the R&D side represented by AFRL, and the post-deployment sustainment organization, WR-ALC. The partnership focused on introducing new technologies and innovative solutions to sustainment, and at the same time, provided clear insight to the R&D community the logistic impacts of early design decisions. This report details the various initiatives performed as well as the overall results of each initiative. This includes TEMS sustainment projects (TEMS SRU TPS Re-Engineering, FFSCU Re-engineering, TEMS EPU Anomaly Detection & Correction, FFSCU TPS, WinDDU Software Port, Processor Card TPS Development) and TEMS Modernization Projects (TEMS COTS Replacement Market Survey, TEMS COTS Replacement Weapon System Survey, UDAS Specification, UDAS RFI &RFP, UDAS Prototype Development, Test & Validation).

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1.0 Introduction

This document is the Final Report under Air Force Research Laboratory (AFRL) contract number F30602-99-C-0214, performed by Giordano Automation Corp., entitled Application of Model-Based Reasoning Tools Used to Enhance and Improve Diagnostic Performance to Improve Air Force Maintenance.

Under the contract, initiatives were conducted to improve the sustainment and modernization of the Turbine Engine Monitoring System (TEMS). TEMS is deployed on the A-10 and KC-135 aircraft to monitor engine parameters and provide alerts to the ground crew upon the occurrence of Malfunction Transactions (MALTRAN). The TEMS system was designed around 1970's technology, and has numerous sustainment issues because of aging and diminishing manufacturing source (DMS) issues.

This program was conducted under a Program Research and Development Authority (PRDA) effort. The efforts represent a true partnership between the two sides of the Air Force that rarely communicate: the R&D side represented by AFRL, and the post-deployment sustainment organization, WR-ALC. The partnership focused on introducing new technologies and innovative solutions to sustainment, and at the same time, provided clear insight to the R&D community the logistic impacts of early design decisions.

This Final Report details the various initiatives performed as well as the overall results of each initiative. The report attempts to describe these initiatives with a broad brush. Additional details on the specific efforts may be found in individual reports that have been prepared and delivered during the contract period.

1.1 Sustainment Projects

- TEMS SRU TPS Re-Engineering
- FFSCU Re-Engineering
- TEMS EPU Anomaly Detection & Correction
- FFSCU TPS
- WinDDU Software Port
- Processor Card TPS Development

1.2 Modernization Projects

- TEMS COTS Replacement Market Survey
- TEMS COTS Replacement Weapon System Survey
- UDAS Specification
- UDAS RFI & RFP
- UDAS Prototype Development, Test & Validation

2.0 Sustainment Projects

2.1 TEMS SRU TPS Re-Engineering

The major objective of this effort was to provide enhancements to the maintenance of the A-10/KC-135 Turbine Engine Monitoring System (TEMS) through implementing the Diagnostician model-based reasoning tool in a selection of Shop Replaceable Units (SRU) level test program sets. This effort included re-engineering of the TEMS SRU level test programs to improve run-time efficiency, accuracy and vertical testability.

The Turbine Engine Monitoring System (TEMS) performs parametric analysis of KC-135 and A-10 engine data. The TEMS unit is mounted on the aircraft. The TEMS LRU and SRU level testing is performed at the Warner Robins Air Logistics Center WRALC in Georgia (previously at Kelly AFB in San Antonio). Since the SRU and LRU level test resources are co-located at the same facility, a rare opportunity exists to analyze the level of test result consistency across the two testers.

In the past few years, the TEMS SRU level-testing software was re-hosted from a VAX controller to a PC controller. At that time, significant inefficiencies in the structure and documentation of the test programs were identified. Inconsistencies were also identified between the LRU and SRU level tests. A proof-of-concept demonstration was conducted in which it was determined that by applying reasoning tools to the test programs, that the run-time speed and test program accuracy were significantly enhanced. At the same time, the structured, engineering process required to implement the Diagnostician resulted in identification of specific problem areas, which could then be resolved. The proof–of-concept demonstration was performed on 091350-RPM Fuel Flow Conditioner circuit card. Table 1 below shows the results of the demonstration.

Table 1 - Diagnostician Benefits to TEMS SRU TPS

Demonstration done on 091350 TEMS A6 Card

Run #	Fault Inserted	Original Time	Diagnostician Time	Time Saved	% Faster	Original Callout	Diagnostician Callout
Run 1	Go-chain	00:23:51	00:15:03	00:08:48	36.9%	Pass	Pass
Run 2	U5.3 SA0	00:22:57	00:06:53	00:16:04	70.0%	U5,U13,U27, U12	U5,U2,U13,U27 Jumper
Run 3	U8.11 SA0	00:13:48	00:05:17	00:08:31	61.7%	AR2,C2,R3,R4	U8,R7,R8
Run 4	U7.13 SA0	00:23:11	00:04:26	00:18:45	80.9%	AR2,C2,R3,R4	U7
Run 5	U28.4 SA0	00:18:45	00:06:23	00:12:22	65.9%	U16,U17,U18,U19,U20,U21,U28	U16,U17,U18,U19U20,U21,U28
Run 6	AR1.10 SA0	00:16:20	00:04:55	00:11:25	69.9%	AR1,R1,R2	AR1, R1, R2
Run 7	U7.11 SA0	00:15:30	00:06:07	00:09:23	60.5%	AR2,C2,R3,R4	U7,R7,R8
Run 8	AR1.3 SA0	00:16:04	00:06:53	00:09:11	57.2%	AR1,R1,R2	AR1, R1,R2
Run 9	U12.2 SA0	00:20:41	00:08:02	00:12:39	61.2%	U12,U3,U16	U12,U3,U16

The demonstration also determined that the commonality of test results between the SRU and LRU level tests could be increased and the mechanism could be put in place to upgrade the re-engineered test programs based on test results and correlation over time and history.

Many of the various TPS improvements came from the run-time characteristics of the reasoning tools as well as the application of a structured engineering process for development of a proper diagnostic knowledge base for use with the Diagnostician. The result of re-engineering the TPSs on the rest of the TEMS cards as part of this project likewise verified the significant improvement in TPS quality in terms of both the Go-chain and the Diagnostic process.

The efforts described in this Final Report were based upon a contract to apply the Diagnostician and the engineering analysis across all of the TEMS Electronic Processing Unit (EPU) circuit cards. The automatic diagnostic reasoning approach that Giordano Automation used in re-engineering the test program sets has been accomplished using a set of tools developed by Giordano Automation. The run-time tool, Diagnostician, provides automated diagnostics that is integrated into the Test Program. The development tool, Diagnostic Profiler, was used to create the Diagnostic models.

2.1.1 SUMMARY OF PROJECT RESULTS

The complexity of the TEMS TPS code has been significantly simplified by inserting the Diagnostician. The traditional troubleshooting trees that were previously implemented with several, hard to maintain GOTO statements, were replaced with a simple conversation loop with the Diagnostician. By eliminating this complex diagnostic hard-coded logic, the resulting TPSs are vastly easier to maintain. Also, transporting the modified TPSs and the Diagnostician to an alternate test resource is much more straightforward. This approach has also allowed for a significant reduction in the number of lines of code for each Test Program as is shown in Table 2.

Table 2 - TPS Project Completion Summary

TPS	Old TPS # Lines	New TPS # Lines	# Old Probes	# New Probes	Go-To's Removed	Modifications Compared to old code
091150	16,468	10,770	58	18	162	Significantly reduced # of probes and code lines
091200	9,715	9,300	76	10	221	Significantly reduced # of probes R1 test was added
091250	10,524	7,492	51	10	219	Significantly reduced # of probes
091300	4,521	6,482	41	28	51	- WB Diag test added to Go-chain to reduce ambiguity - Runs R76 & R4 first to reduce ambiguity - WB, NB & VIBCLK tests results are displayed in log files as applied - Tolerances were tightened accordingly
091350	28,524	11,532	117	50	1401	Reduced # of probes
091450	Combined w/ 091460	-			Combined w/ 091460	- Combined 091450 & 091460 TPS's to one linked ATLAS program
091460	16,553	24,551	57	29	732	Added a calibration test to the potentiometer on the 4.9 Volt Reference Test.
9383755	N/A	12,436	N/A	28	N/A	New Program.
091600	78,589	14,099	113	72	1422	Combined all 4 old mod code into 1 linked TPS program
091650	55,493	8,851	69	30	1804	Combined all 6 modules into 1 linked program
091750	19,977	-	86	-	-	

The overall test results have been significant in that we see a vast improvement in the overall diagnostics, a reduction in the amount of probes in general on each individual board, and the re-orientation and modular structuring of the test program to allow it to be easily migrated to another functional test system. In addition, the Diagnostic Profiler can be applied directly to those comparable tests on any migrated test system to allow capturing of the diagnostic data as you migrate from one tester to the other. This would be a significant reduction in overall test program costs in migration of the test programs to alternate functional test system. All appropriate Software Delivery Forms for the various assemblies test programs that have been certified through the LYSTA organization of the Warner Robins Air Logistic Center (WRALC) Software Development department were transmitted to the TEMS Equipment Specialist for displacement and disposition for use on the MATE 390 Test System.

In general the test programs have been dramatically improved on the go chain to increase accuracy where correlation problems have existed between the LRU and the SRU test system. A major improvement was to modularly separate the various test program sub-sections into modular stand-alone tests, which can be easily maintained, de-bugged and transported. In addition, all documentation and supporting information is provided to the Air Force as part of this contract in order to allow total organic maintenance and support of these Test Programs in the future. Due to the use of the Diagnostician, a more accurate and efficient resolution to the specific component failure is realized with the upgraded diagnostics. The diagnostic process for the boards all exhibit a reduction of the number of probes from the previous test programs in order to accomplish an improved diagnostic environment. In addition, the more complicated "fault tree" approach to diagnostics has been eliminated. In effect, a model has replaced the manual fault tree depiction of the individual probe processes. The diagnostic model is much easier to maintain and upgrade and support as any discrepancies or anomalies occur. A major benefit is that the diagnostic process through the Diagnostician allows a direct application and migration to a migrated test program on another Test platform as the MATE 390 is phased out in the future.

2.2 FFSCU Re-Engineering

The Fuel Flow Signal Conditioning Unit (FFSCU) is an airborne LRU that reads fuel flow data and provides a corresponding input to the TEMS EPU. The TEMS FFSCU has become a critical sustainment issue for TEMS. The FFSCU was originally designed in the 1970s. Since its inception it has been proprietary to the OEM. The government has no knowledge of the electronic circuitry of the FFSCU or the input signal profile and has been unable to develop organic test or repair capability for the unit. The OEM is the sole repair and manufacturing source. Repair costs escalated to $10,000 each in 1997. The OEM has been increasingly unresponsive to Government requirements for repair of units. This is primarily due to the age of the item and relatively low demand rate on the part of the Air Force. As a result, several years ago, the OEM had raised the cost of repair of FFSCU units to approximately 10K per unit.

Due to these problems with repair of the FFSCU, and the fact that the requirement had become critical to A-10 operations (as a MICAP reportable item), the TEMS System Manager decided to look for an alternate source for FFSCU spares and support. They located Apex Signal, a company with extensive experience with FFSCU requirements. The APEX engineers discovered that the original design contained a potted brick that was not field repairable and was no longer available as a standard product because it contained many obsolete components.

The TEMS System Manager initiated a project to re-engineer the FFSCU by a new manufacturer, and, at the same time, provide the organic AF depot with the capability to test the FFSCU.

The original intention was to re-engineer a FFSCU to the exact specifications of the original FFSCU. Subsequent discussions with the A-10 System Program Director (SPD) resulted in the A-10 requirements for a FFSCU that complies with an updated set of specifications for the A-10 aircraft. A new specification was developed, and the vendor is currently in the process of performing independent laboratory tests for acceptance of the FFSCU. When these tests are successfully completed, flight tests and flight qualification will be initiated with the A-10 SPD.

A contract was put in place to accomplish the following:

1. Update the design with new components to eliminate the obsolete components
2. Repair a total of 29 units by either salvaging good modules from returned units or replacing failed modules with the revised layout.
3. Generate a functional test process and associated hardware/software to accomplish this testing as an organic Air Force process.
4. Provide design documentation (schematics) at a level necessary to allow for organic AF functional testing.

This was subcontracted as a low-cost effort (130K), not a major re-design program. The goal was to get units out in the field to support operations quickly and efficiently.

The only environmental requirements placed in the statement of work were that “Any newly designed circuit elements shall meet the following environmental specifications: Withstand altitude excursions from -250 to +70,000 feet, and Withstand temperature excursions from -65 F to +165 F.”

The A-10 SPD understood this to be a new design of the FFSCU, and therefore, sought to place full, updated and modern environmental testing on the unit. These requirements were above and

beyond the original FFSCU specifications, and required more extensive design work and extensive environmental testing be accomplished by APEX, which were beyond the scope of the original subcontract.

It is important to point out that the FFSCU is failing due to typical aging problems, not due to environmental stresses on the unit. Further, it is important to note that the FFSCU is totally passive in the A-10. It does not interface with the fuel lines.

Based on A-10 updated requirements for environmental characteristics of all items being put on the aircraft, the initial effort was stopped by the TEMS Program Manager. The program was re-initiated as a FFSCU re-design effort to satisfy A-10 environmental requirements under a separate contract.

Under that effort, Giordano Automation worked with the A-10 SPD to identify updated environmental requirements, and prepared an updated FFSCU requirements specification, which was coordinated through the TEMS office and the A-10 SPD. A new effort was initiated with APEX based on the updated specification.

The plan is to test the updated design through an independent laboratory, and then conduct flight-testing. Subsequently, under a separate contract effort, a test program set for depot testing was prepared on the APST test system in Warner Robins and has been sold off for use in Depot testing of the FFSCU.

Once APEX completes the Environmental and EMI testing through an independent test lab, the A-10 SPD and Giordano Automation will coordinate flight-testing and certification of the FFSCU units repaired under the new repair process and source.

2.3 TEMS EPU Anomaly Detection & Correction

The A-10 aircraft was experiencing high rates of a vibration fault call-out (MALTRAN Event) in the field that could not be duplicated in the depot. In this false call-out, the EPU reports excessive vibration, ranging from 30 to 250 mils, and the aircrew reports no occurrence of excessive vibration. The upper tolerance limit for vibration is 4 mils. Since this failure requires a maintenance action before the aircraft can be returned to flight operations, the ground crew would replace the EPU to resolve the failure and turnaround the aircraft. This situation resulted in a high level of Cannot Duplicate (CND) rates for the TEMS EPU. At the depot, no failures could be found on these EPUs.

Giordano Automation was tasked to investigate the problem, and develop and document a process for the detection of this problem in the EPU depot, and the subsequent repair, or correction of this problem. In support of this task, Giordano Automation subcontracted with the EPU OEM, Northrop Grumman Corporation.

The investigation revealed that this A-10 TEMS Vibration Event is caused by the EPU corrupting the digitized vibration signal. The corruption is caused by growth, on the EPU motherboard and enclosure, of a foreign substance, which contains sulfur (likely residue from firing of the cannon on the A-10). The accumulation of this growth, exacerbated by high amounts of moisture intrusion into the enclosure, causes a shorting out of components under certain flight circumstances.

The investigation further resulted in finding that the current depot test processes at the LRU level were not comprehensive enough to uncover these problems. A more comprehensive test and inspection process has been defined and documented. Properly implemented, these processes should significantly decrease this nuisance situation for A-10 flight and ground crew and the cycling of TEMS units through repair cycles.

2.3.1 DETAILED EFFORTS

Because of the high rates of the vibration anomaly in the field, user groups noted the repeat problem units and began tracking by serial number. Tracking by S/N is not always done in the repair process. Units were cycled through the repair facilities with no detected problems and were recycled as serviceable. Once the depot determined the problem was remaining with certain EPUs, these EPUs were taken out of the repair cycle. These EPUs were used in the investigations performed.

The EPUs with known serial numbers that exhibited the problem were cycled through an extensive test process at Northrup Grumman Group (NGC) which included testing at a variety of environmental excursions. The units were then followed to a user destination where their flight operation was closely monitored.

A variable that greatly influences this investigation and has much to do with data collection in general in the A-10 EPU, is the environmental location of the unit and the fact that it is not sealed. Extensive moisture collects in the compartment, rack mounting, and cable connector shells in the A-10 aircraft. There is a vent to the compartment that allows driven rain to enter.

NGC determined that a corrosion is formed on the underside of the “motherboard” which is located next to the inside base of the EPU. The mother board is the printed circuit module that holds the 13 electronic circuit card edge connectors (CCAs) in the EPU and distributes all the interconnects between these CCAs and the outside connectors. The corrosion is forming, over time, on the motherboard, at a location directly over one of the drain holes located in the bottom of the EPU housing. Although all of the printed circuit modules in the EPU are “conformal coated”, but, in time, the corrosion wins. The troublesome area is not visible unless the motherboard is removed; an extensive inspection process not normally conducted during depot repair. The process of removing the motherboard, inspecting it and cleaning it, and re-coating has been added to the depot repair process.

Further, the problem can only be *detected* in the repair facility only during temperature excursion testing. The low-end temperature specification is -54 degrees C. NGC found that none of the units would pass tests below a temperature below -45 degrees C. It was recommended that the repair facility test process will be amended to operate the EPU under test at the –45 degree C to detect the vibration anomaly.

A further part recommendation was to seal the two drain openings directly beneath the corrosive area forming on the motherboard. There will still remain 4 drain holes in the bottom of the EPU housing.

A side point; conformal coating will not seal the junction where the CCA edge connector plugs into its mating counterpart on the motherboard. This condition exists in all electronic devices. If enough moisture collects inside the housing, it will accumulate in those many junctions where the pins mate to sockets. A sealed pin-to-socket connection is almost impossible unless the whole unit is sealed and pressurized. Any plans to re-engineer the EPU should include that feature.

Another recommendation is that A-10 SPD aircraft manager assistance is required in the matter of correcting the problem of exposure to excessive moisture.

It was recommended that further investigation should also be performed to determine if the TEMS EPU housing/chassis is involved in the ground return of the complete system. If the aircraft 28 Vdc power system relies on the aircraft chassis as a ground return circuit, and the same applies to some or all of the sensor signal cabling, it is imperative that the physical connections between EPU chassis and aircraft are corrosion free. Corrosion does exist at these junctions. The socket/pin connections between the EPU chassis and aircraft mounting rack can and do become excessively corroded in the A-10. Sensor signal corruption in aircraft can be traced to this condition. To save a great deal of weight in aircraft, it may be that one copper conduction wire was used throughout rather than including a second as a signal return path. If the aircraft chassis is involved in ground returns, “ground loops” can exist which cause many problems in the discipline of data acquisition.

A report documenting the findings and the test process was prepared and delivered.

The figure below identifies the test and field investigation cycles for each EPU, by serial number, that was cycled through the investigative process.

Table 3 – EPUs and Field Investigation Results

Part Number	9058027-10ROR					
S/N	020008					
Shop Order	W083215					
Present loc.	In Aircraft					
Date	7/26/2000	9/11/2000	9/11/2000	9/18/2000	11/14/2000	11/22/2000
Failure	Vib reading of 34.0 sb <.5	Vib readings of 0.6 sb <0.5	No Power	No Failures Unit Passes all Tests		
Action	Clean Mother Board	Swap 091300-302 S/N 0200165 with S/N 0290104 from EPU 15	Swap 091750-301 S/N 0100524 with S/N 0100660 from EPU 15		Flew 2 failure Free Sorties @ NAS New Orleans	Sent Out
Temp	Amb..	Cycles	Amb..			

Part Number	9058027-10ROR						
S/N	0290481						
Shop Order	W083214						
Present loc.	NDMP Receiving						
Date	6/26/2000	9/11/2000	9/18/2000	11/14/2000	11/22/2000	1/10/2001	1/30/2001
Failure	HIDC intermittent	DCS1-6	No Failures Unit Passes all Tests			Came back from NAS New Orleans	
Action	Clean Mother Board	Swap 091250-302 S/N 0200720 with S/N 0290619 From EPU 15		Flew 2 failure Free Sorties @ NAS New Orleans	Sent Out	Ran atp and flight sim during cycles no failures reported	sent out
Temp	Cold	Cold				various	

Part Number	9058027-10ROR					
S/N	0290231					
Shop Order	W083216	W087690				
Present loc.	Para					
Date	6/26/2000	7/5/2000	7/24/2000	7/27/2000	8/7/2000	9/11/2000
Failure	Multiple	Vib Failures	Vib Failures	Multiple	No cold Boot	Vib Failure 1.2 sb < 0.5
Action	R/R U3 on 091460-301	Clean Mother Board	R/R C28 on 091800-305 Wire 43 pinched on 091760-304	R3,U3,C1 on 091460-301	U3 on 091800-305 Swap 091750-301 S/N 0190189 with S/N 0100524 from EPU 15	Swap 091460-301 S/N 0190163 with 091450-310 S/N 1000309 from EPU 15
Temp	Amb..	Cycles	Cycles	Cold	Amb.	Cycles
Date	9/13/2000	12/4/2000	1/10/2001			
Failure		Failed @ NAS New Orleans				
Action	Sent Out	Failed initially @NDMP but then never failed again	Sent Out			
Temp		Amb.				

Part Number	9058027-10ROR					
S/N	0290015					
Shop Order	W083213					
Present loc.	NDMP Test					
Date	7/5/2000	9/5/2000	9/11/2000	1/11/2001		2/5/2000
Failure	Left Thermal Couple	Multiple		Multiple		
Action	Swapped 091020-301 S/N 0190793 with S/N 0100276 From NDMP Test	Clean Mother Board	swapped: 091450-310, 091300-302, 091750-301, 091250-302	R/R R11 on 091250 R/R CR15 on 091800 R/R C17,C18 on 091300	Ready for retest	Ready to ship
Temp	Amb..	Amb			various	

2.4 FFSCU TPS

A subcontract was placed with TRW SAEO for the development of a Test Program Set (TPS) for the TEMS Fuel Flow Signal Conditioning Unit (FFSCU). The FFSCU TPS would enable the Air Force to have organic screening capability for FFSCU units, a capability that was not in place at the time. All units returned from the field had to be sent back to the OEM for repair. The FFSCU TPS was designated to be developed on the IABIT tester.

Under this effort, typical test program set development milestones were established, including Software Requirements Review (SRR), Test Strategy Document (TRD) development, Preliminary Design Review (PDR) and Critical Design Review (CDR), as well as appropriate milestones for Technical Manual development.

TRW expended all funding on this effort before being able to deliver an end product. The Air Force was not able to secure the additional funding required to complete the project.

The IABIT tester was subsequently put out of service by the Air Force, since it was inoperable. GAC created a TPS for the FFSCU LRU on the APST test system in Warner Robins ALC, and the Air Force now has an organic capability to test and verify the FFSCU assembly.

2.5 WinDDU Software Port

A subcontract was placed with TRW SAEO for porting the DOS-based TEMS Data Download Unit (DDU) software to a modern, Windows software environment. This included re-design and re-hosting.

The Win DDU software was completed and delivered to the Air Force by TRW. Subsequently, certain test problems and field correlation problems were seen and recorded which are being corrected by OC-ALC engine management group as they apply to engine test algorithm anomalies.

2.6 Flight Simulation Software

A subcontract was placed with TRW SAEO for porting and enhancing the TEMS flight simulation software, which resided on the TEMS OEM's tester called the "Loop Tester" to a modern test environment. The Flight Simulation program would have allowed the Air Force to perform dynamic testing of the TEMS EPU by simulating the inputs that the EPU receives in the operational environment. The result would have been a much more extensive test capability for the EPU. This effort was being hosted on the IABIT test system at WR-ALC. The IABIT tester was subsequently put out of service by the Air Force, since it was inoperable.

TRW expended all funding on this effort before being able to deliver an end product. The Air Force was not able to secure the additional funding required to complete the project.

2.7 TEMS EPU Processor Card TPS Development

A test program set was developed for the EPU Processor card and a re-engineered version of the Processor card. A test program had not previously been available for the processor card, so this resulted in a new and improved test capability for the depot.

GAC created a TPS for the Slot A9 processor card on the MATE 390 test system in Warner Robins ALC, and the Air Force now has an organic capability to test and verify as well as diagnose and repair the processor assembly for the KC-135 and A10 EPU assemblies.

The test program set included full documentation and was successfully sold off (verified and accepted) at Warner Robins Air Logistics Center depot operations. A software Computer Program Identification Number (CPIN) was provided and delivered, fault insertion diagnostics were performed and verified to support a diagnostic repair capability, and supporting Test Program Instruction (TPI) tech orders were provided and delivered.

3.0 TEMS Modernization / Replacement

The Turbine Engine Monitoring System (TEMS) is currently used in the A-10 and KC-135 aircraft. TEMS is a 25-year-old technology *system*. Obsolescence of individual components is rendering it unsupportable.

This system utilizes one Electronic Processing Unit (EPU) in the A-10 and two in the KC-135. The three housings and cable connectors are identical. The differences are the aircraft and engine sensor signals received from the two engines on the A-10 and the four engines on the KC-135.

The TEMS EPU houses the electronics that samples, digitizes, and stores analog signals received from engine and aircraft sensors. Due to the nature and function of the referenced weapon systems, the range of interest, magnitude, frequency, and quantity of sensed signals are not identical.

In the current configuration of TEMS, the operating system (O/S) and decision-making, algorithmic, programs are stored as *firmware* in EPROMs in the EPUs. Sensed parameter limit values and reference constants are stored in RAM. The TEMS EPU performs algorithmic activity and stores all sensed data values when certain conditions are satisfied. At three points in the flight profile, TAKEOFF, CLIMB, and CRUISE, the data is stored if the algorithmic activity senses certain parameters are <u>within</u> stored data limits. For 51 other weapon system operating conditions, the data is stored if certain parameters are fixed <u>outside</u> stored data limits (EVENTS).

Besides storing the three automatic data points, the existing system stores data generated by an EVENT only once. Triggered by a switch in the cockpit, data storage can be initiated by the Pilot. Data from multiple flights can be stored between downloads.

The limit values, called CALMEM, and Actuarial data are stored in RAM with the “Initializing” process. This process transfers these constants to the TEMS EPU via ground support equipment (GSE). “Downloading” is the existing process whereby GSE is used to retrieve the stored flight data.

The current EPU uses aircraft 28 VDC aircraft power. It is also designed with battery backup to retain volatile RAM memory. The existing module is not pressurized but open to the atmosphere. These latter two features along with the EPROMs, 8055 Processor, data sampling speed, component obsolescence, and seventies signal conditioning technology contribute to excess system operating costs.

Under this contract, a series of tasks were performed to derive a suitable, cost-effective candidate for the replacement of the TEMS system.

3.1 TEMS COTS Replacement Market Survey

A Market Survey was performed to determine the availability of candidate replacement systems on a Commercial Off-the-Shelf (COTS) basis.

A pre-cursor to the actual Market Survey was the definition and documentation of critical performance parameters for the TEMS. This resulted in a TEMS Performance Specification that was then converted to a Commercial Item Description (CID).

The Market Survey was primarily performed by TRW SAEO. The market survey included soliciting inputs from vendors to understand the capabilities of available commercial flight data recorders that may be capable of performing the tasks required for a replacement of the TEMS. This survey included contact with industry associations, vendors, literature search, brochure and catalog reviews, and on-line searches. The results of the survey were then analyzed against the previously defined performance parameters.

The results of the Market Survey are documented in a Market Survey report. The market survey was specifically targeted towards the availability of a COTS replacement of the TEMS on the A-10 aircraft. The market survey determined that there are no systems that could replace the TEMS on the A-10 without a Non-Recurring Engineering (NRE) effort. The survey also found that there were no systems currently offered that are designed with open architecture standards that satisfy the goal of long-term non-obsolescence.

A questionnaire was developed to identify key technology areas and vendor capabilities in order to assess the potential for having the A-10 TEMS requirements satisfied using COTS or primarily COTS-based solutions.

Table 4 – Market Survey Questions

1	Model Name?
2	Part Number?
3	Flight Certified? (Y/N/Pending)
4	A/C used on?
5	Number of Analog Input Channels?
6	Are Analog Inputs/Channels Configurable? (Y/N)
7	If Q6 is Yes, to what extent are analog channels configurable? 0-10V, 0-1V, 0-100 mv, 4-20 ma ,etc.
8	Number of Discrete Input Channels?
9	Are Discrete inputs/channels configurable? (Y/N)
10	If Q9 is Yes, to what extent are discrete inputs/ channels configurable? 0-5V, 0-28V, dry or wetted contacts,
11	Number of Thermocouple Channels?
12	Types of Thermocouples supported?
13	Number of Synchro Channels
14	Number of accelerometer pickup channels supported?
15	Can system measure narrow band and wide band vibration on each channel? (Y/N)
16	Number of RPM / frequency measurement channels?
17	Number of Mil STD 1553 buses provided?
18	What 1553 modes are supported? Full/RT/Other
19	What is system memory size In MB?
20	What is trending data storage memory size in MB?
21	What standard configuration interfaces are supported?
22	What is the ADAS unit's power consumption in Watts?
23	What is the weight of the unit, in lbs?
24	What is the unit's MTBF?
25	How is the MTBF Determined? Is it based on calculation or demonstration?
26	What altitude is the unit rated for? (in Feet)
27	What is the humidity specification limits for the ADAS unit?
28	What are the Vibration Limits for the unit?
29	What are the shock vibration limits for the ADAS unit?
30	What are the temperature (op/ storage) range/ limits for the ADAS unit?
31	What Operating System does the ADAS unit use?
32	What software programming languages does the unit use?
33	Is the embedded application software proprietary?
34	How is ADAS configured? Laptop/ Peculiar Device. (L/P)
35	Is the ADAS unit ground support software proprietary or can source code be provided?
36	How is ADAS configuration data retained? Battery, Flash, EPROM or other.
37	If other, What technology is used?
38	Can embedded application be updated via hardware I/F or is it contained in firmware? (U/F)
39	How many years in service?
40	Does system have an A/C mounted interface for interrogating ADAS status?
41	Where is this ADAS system designed to be mounted?
42	What are the dimensions of the ADAS unit?
43	What is the warranty for this ADAS unit?
44	Does the ADAS contain a built in test (BIT)?

45	Does the unit have calibration requirements?
46	Is a repair facility available for this system?
47	What is the Cost of the standard ADAS unit?

Table 5 summarizes the information collected for the vendors who have requested the questionnaire in order to provide data for potential candidate solutions.

Table 5. TEMS Source/Vendor List

VENDOR INFORMATION	CAGE CODE	MODEL NO.	PART NO.
AMETEK 50 Fordham Rd, Wilmington, MA 01887	4A887	EMSC	8KE124
		AVM	8KE143
		EAU	8KE131
		SCDU	8KE89
BAE Systems – Canada 415 Legget Dr., PO Box 13330 Kanata, Ontario, Canada K2K 2B2	38753	CMA-2074MC	**(TBD)**
CPU-Tech 4900 Hopyard Rd., Ste 300 Pleasanton, CA 94588	0XRH7		
Honeywell-Altair 106 Access Rd., Norwoord, MA 02062	08CZ0	TrendCheck	TREND-A-010-1
		ADAS	TWIN-A-010-1
		IntelliStart+	DPU-A-010-1
		NIU	2118908-4
Hamilton-Sunstrand One Hamilton Rd., Windsor Locks, CN 06096	6H521	SDC200-20	791660-30
		DAS100-1	
R-NET Engineering & Technologies PO Box 2418 Cedar Rapids, IA 52406	1P1T5	ADAPTS-B	
		ADAPTS-10	
		ADAPTS-16	
		ADAPTS-CBM	
SBS Technologies 2400 Louisiana Blvd., NE Albuquerque, NM 87110	0BAS8		
Smiths Industries 3290 Patterson Ave., SE Grand Rapids, MI 49512	0B0W7	Voice and Data Recorder (VADR)	3253A
			3253C
			3253E
			3253F
Teledyne Controls 16151 NE, 113th Court Redmond, WA 98052	98571	DFDMU	
		DMU	
		FDAU	
		FDIMU	
		MDAU	
		MFDAU	

3.2 TEMS Replacement Weapon System Survey

Towards the end of the Market Survey effort, Air Force senior management direction was given to emphasize and pursue system architectures that could be used across multiple aircraft platforms using open architecture concepts. Additionally, direction was put forth to identify additional Air Force aircraft platforms that were experiencing the same obsolescence issues, as was TEMS, and to define a system that could be used on a common basis.

The concept was that TEMS replacement could be the first step in improved aircraft readiness and maintenance across AF weapon systems by taking advantage of 25 years growth in technology. KC-135 and A-10 are the first TEMS-like systems to face the challenges of obsolescence. Other TEMS-like applications implemented over the past two decades will face similar obsolescence over time. Some aircraft have either no monitoring capability or limited monitoring capability. TEMS replacement for A-10 / KC-135 can lead to many new and exciting opportunities for the AF propulsion and support communities. Updated TEMS hardware facilitates extended utilization/processing of parametric data such as life usage indicators, anomaly detection and snapshot, embedded diagnostics, prognostic indications and trend analysis. The opportunities presented by a redesigned TEMS include developing a common core module, open architecture, accommodate legacy systems while allowing enhanced diagnostic/prognostic processing, data reduction through intelligent processing, significantly reduced ground support equipment and significantly reduced support costs. Other opportunities include joint service applicability and interest, expanded functionality, expanded memory and expanded intelligence in ground processing.

In the course of the survey, program offices (SPOs) were contacted and the following information was attempted to be gathered and characterized:

- Does the system currently have a Data Acquisition, Analysis, and Forecasting System capability?
- If not, is a Data Acquisition, Analysis, and Forecasting System capability warranted?
- Is the program office receptive?
- How are engine diagnostics and trending currently accomplished?
- If a Data Acquisition, Analysis, and Forecasting System capability is in place:
    - What is the age of the current system
    - Are there obsolescence issues? Supportability issues?
    - What sensors are incorporated?
    - Is there a data bus in the system?
    - Is the Data Acquisition, Analysis, and Forecasting System used for:
        - Engine Go/No-Go at flight line
        - Engine Diagnostics at flight line
        - Input to Comprehensive Management System (CEMS) IV/Comprehensive Engine Testing and Diagnostics System (CETADS)?
    - Who is the Primary Focal Point concerning this Data Acquisition, Analysis, and Forecasting System?
    - How long is the aircraft expected to be operational?
    - Is there interest in updating the Data Acquisition, Analysis, and Forecasting System?

As a result of the survey, several aircraft platforms were identified that had a need for a modernized data acquisition system. These include F-16, F-15, KC-10, F-117.

3.3 UDAS Specification

Based on the re-direction from senior Air Force management, the program was re-cast to develop a concept and system architecture that could be adapted across multiple aircraft platforms, without requiring expensive wiring and connector changes to the aircraft.

At the same time, the A-10 SPD opted out of a replacement system for TEMS, opting instead for short-term fixes to the TEMS EPU. Additionally, KC-135 planned a consolidation of data acquisition functions into a single recorder, and retirement of the TEMS system from use on the KC-135. The F-16 aircraft was facing immediate, critical need for a replacement of the F-16 Crash Survivable Flight Data Recorder (CSFDR) and strongly supported the open architecture concepts. The program was re-focused on this F-16 requirement.

A system concept was defined for a Universal Data Acquisition System (UDAS). UDAS consisted of a common core of those elements that were common to any flight data acquisition system, and an aircraft interface module, which were the unique elements that adapted the overall system to the requirements and interfaces of a specific aircraft platform.

A performance specification was developed defining this overall system concept and architecture. The specification included a primary specification for the overall architecture and the requirements of the common core, and was augmented with a platform specific specification. The F-16 CSFDR replacement was selected as the target application as a proof of concept. Therefore, the platform specific specification reflected the specific requirements for replacement of the F-16 CSFDR by a universal data acquisition system.

3.4 UDAS RFI & RFP

Based on a system description and the specifications described in the previous section, a Request for Information (RFI) was developed and released to industry through the Commerce Business Daily (CBD). The intention of the RFI was to identify potential Industrial Sources for a system as defined in the specifications, and to validate the system concept by soliciting comments and specific technical approaches.

Many responses were provided to the RFI. The RFI responses were also used to determine if it would be feasible for our program to solicit proposals for the development of a prototype UDAS system (e.g., were there enough funds remaining to develop the prototype.) The RFI responses were also used to refine the specification, identify risks, and to develop a statement of work for the development of the prototype.

As a result of the RFI results, it was determined that is was indeed feasible to develop a UDAS prototype. A full set of procurement documents was developed and compiled into an RFP package. An RFP was released to industry via an announcement in the Commerce Business Daily.

Eight proposals were submitted in response to the RFP. An extensive evaluation of the proposals was conducted. Only one company’s proposal met the full set of technical requirements and was

within the cost range. A subcontract was awarded to R-Net Engineering and Technology for the development of a prototype UDAS system that would target the replacement of the F-16 CSFDR.

3.5 UDAS Prototype Development, Test & Validation

A subcontract was awarded to R-Net Engineering and Technology for the development of a prototype UDAS system that would target the replacement of the F-16 CSFDR. The overall purpose of the prototype development was to serve as a proof of concept and validation of the UDAS specification, and at the same time, to develop a system that would serve as a feasible candidate replacement for the F-16 CSFDR.

The UDAS was tested on the F-16 CSFDR hotbench facility at Lockheed Martin in Ft. Worth, Texas. The testing verified the functionality and feasibility of the UDAS.

The following provides a description of the results of this prototype development effort.

3.5.1 Universal Data Acquisition System (UDAS) Program Summary

UDAS is a data acquisition system that is being developed as an open-architecture device that can be adapted to any aircraft application. In the current application, it is being targeted as a form-fit function replacement for the F-16 CSFDR. For this application, all F-16 blocks will be accommodated using a single design, which reconfigures to the specific block aircraft TMS via software.

UDAS uses the latest, state-of-the-art technology for architecture, system memory, data processing and storage, and crash survivable memory. It has system hooks for the implementation of wireless transmission of signals and data, as well as video and audio data collection and storage.

Our goal in the UDAS program is to significantly reduce the cost, and improve the long-term supportability posture of data recording systems including Crash Survivable Flight Data Recorders through the use of standard open architecture design concepts applied to the hardware and software of the device. It is also to define and substantiate an architecture that is readily adaptable to any aircraft platform needs via augmentation of the core (common) hardware and software elements with aircraft-unique elements.

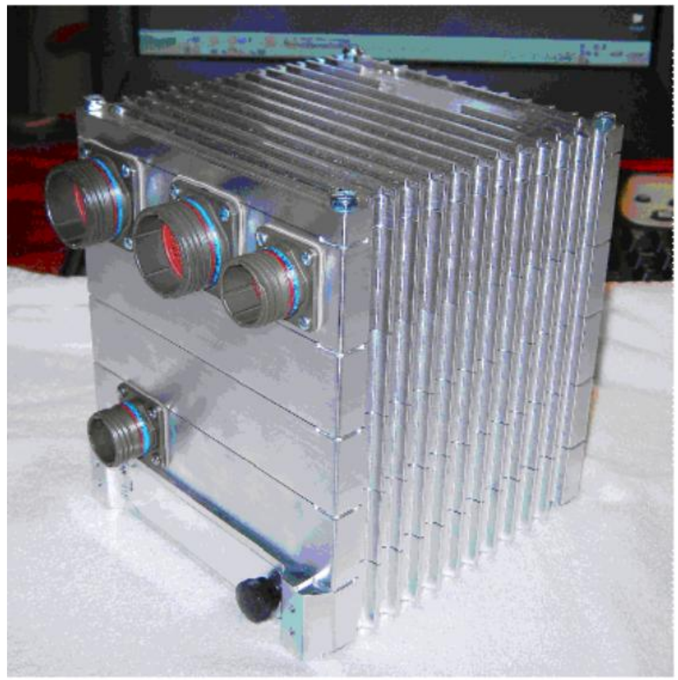
The UDAS design is based on the use of commercial design standards in a ruggedized, military environment. PC/104-Plus architecture is used with a Linux Operating system.

3.5.2 UDAS Program Accomplishments

The UDAS Program has completed the development of the common core UDAS data acquisition system, and has developed a prototype that is specifically designed to meet the requirements of the F-16 Crash Survivable Flight Data Recorder (CSFDR). The unit has been tested on the CSFDR hotbench facility at Lockheed Martin and successfully read simulated flight profiles and performed data handling correctly.

The accomplishments in the UDAS development effort include the following:

- Open Architecture Design with "Common Core" that can be applied to multiple aircraft applications
- Designed around Open Industry standards (PC/104, Linux)
- Common Design and Support Infrastructure
- "True" COTS (no mods)
- Form-Fit-Function Replacement with NO Aircraft Mods
- Built-in Non-Obsolescence
- Significantly Reduced Costs
- Non-Proprietary
- Easily Expandable through Plug & Play
- NOT *"One Size Fits All"* – Re-Configurable to platform requirements
- Use of signal and parameter names that can easily be read by people (English language in engineering units).



3.5.3 Adaptable Design for Multiple Aircraft Applications

Common Data Acquisition Module (CDAM)
- Hardware
- Software

+

Host Aircraft Interface Module (AIM)
- Hardware
- Software
- CSM (if required)

=

Host Aircraft UDAS

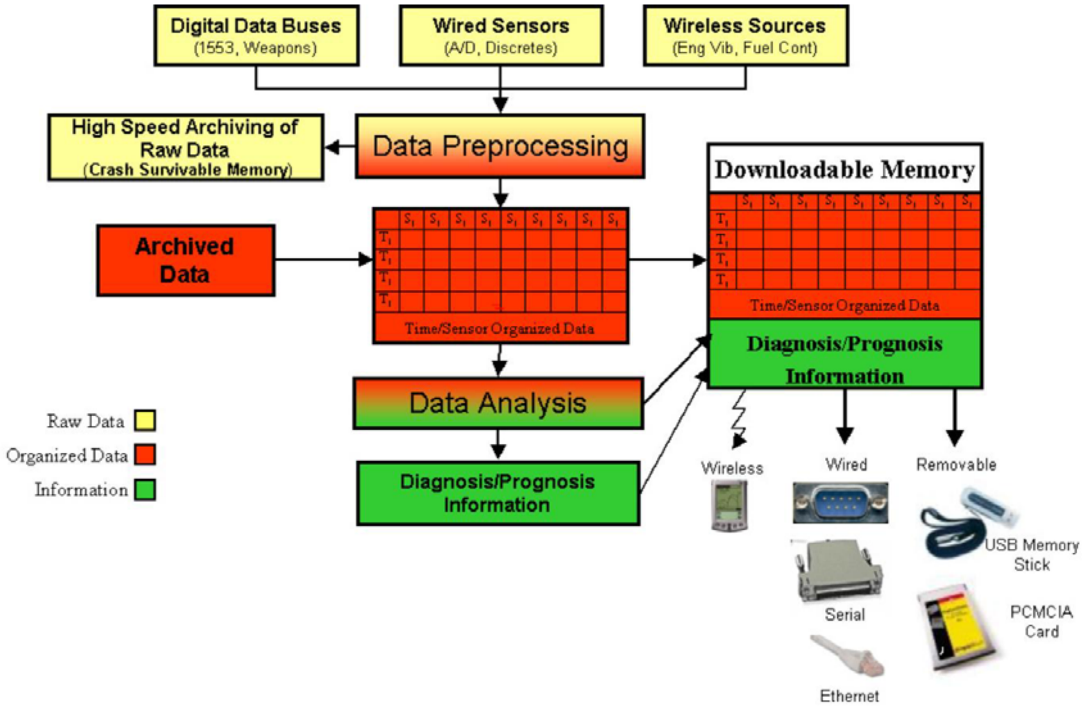
Includes…
- CPU
- System memory
- Power Supply-
- Operating System
- I./O Card Driver Library
- Data Processing
- Data Analysis

Includes…
- Electronic Interface (I/O Cards)
- Physical Interface
- Processor enclosure
- CSM mounting
- System I/O Configuration
- Unique Data Analysis

3.5.4 UDAS Data Structures / Data Handling

Generic data structures have been designed to accommodate the requirements of the AF AIP (Aircraft Information Program). These data structures allow collection of all data into a matrix format, and extraction of required data for off-line processing routines via simplified queries against the matrix.

The graphic below illustrates the flow of data into, through, and from the UDAS system. Raw data can come from digital data buses such as the MIL-STD-1553 avionics and weapons digital data buses, from wireless sensors, and from wired (copper or optical) sources.



Raw data is digitized as needed and, if desired, selected raw data is routed to crash survivable memory before any processing occurs. Initial data processing involves transforming the raw data into readable, engineering units, associating each data stream with its sensor source, time tagging the data, and then entering all data from all sources into a time-source correlated database. This time-source data is then stored in non-volatile memory. Archived data that had been loaded into the UDAS system prior to flight is also moved to the database to facilitate prognostic analysis. The correlated data is then processed to produce diagnostic and prognostic information and the processing results transferred to the non-volatile memory. The correlated data and information can be downloaded in whole or in selected parts via data radios in real time or after landing using wireless hand held device, through a standard serial connector, and/or through removable memory. Information can also be routed back to the aircraft system through the digital data buses.

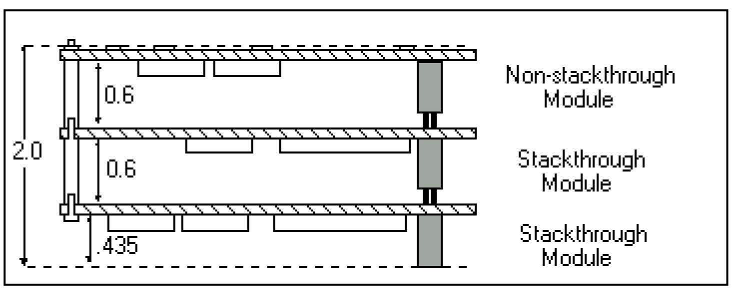
Data source methods (digital data bus, wireless, wired) are selectable for the original design and equipment. Additional data source methods and data streams can be added as needed after the equipment is initially installed. The data/information download method can also be selected initially and changed after installation. Data analysis processes are changed as needed by software update.

3.5.5 UDAS System Architecture

The UDAS system employs the PC/104+ with a 32-bit PCI backplane. The PC-104 architecture features:

- Self-stacking modules 104-pin and 120-pin PCI bus connectors to allow multiple modules to be added to the system with out the burden of backplanes and cartridges.
- Minimized size (3.6 x 3.8 in)
- Low power consumption (typically 1-2 watts per module)
- PC/104-*Plus* technology is compatible with PC/104 and supports 32-bit PCI interconnect
- Consortium companies with company products and specifications

Standalone module stacks. As shown in the figure, PC/104 modules are self-stacking. In this approach, the modules are used like ultra-compact bus boards, but without needing backplanes or card cages. Stacked modules are spaced 0.6 inches apart. (The three-module stack shown in the figure measures just 3.6 by 3.8 by 2 inches.) Companies using PC/104 module stacks within their products frequently create one or more of their own application-specific PC/104 modules.



PC/104 Background Information[1]

The x86-based PC has made an enormous impact in the computing world that has spilled into the industrial and non-desktop market as well. The PC architecture has become the dominant standard that has worked its way into applications never dreamed of by its designers. The reason is that an embedded PC can reduce development costs and accelerate their time to market. The standard it brings is more than just bus timing or packaging. PC-compatibility means a definition of the internals of a system including the CPU family, DMA, interrupts, timing, serial ports, LAN interfaces, video, disk storage, etc. The bottom line is that the PC has become firmly embedded as a standard design element in a wide variety of applications.

Introduction of PC/104
Embedded designers have reaped a bonanza from the PC. One of the finest examples is the PC/104 architecture whose first specification was published in 1992. Key features/benefits are that the modules are compact, modular, self-stacking, and PC-compatible offered in a variety of functions with multi-vendor support. Also, there is an active Consortium to maintain and improve

[1] Excerpted from a White Paper by Robert A. Burckle, VP, WinSystems, Inc.

the technical standards plus promote worldwide industry visibility.

PC/104 is a repackaged, modular version of the PC architecture intended for embedded applications where space, power consumption and reliability are critical. These modules can serve as a mezzanine bus for an embedded System Bus Controller (SBC) or it can become the entire computer and I/O system.

A PC/104 module is an Industry Standard Architecture (ISA) bus board reduced to 3.6 x 3.8-inch (90 x 96-mm) that is approximately the size of a 3.5-in diskette. The bus signal definitions and timing are the same. PC/104's P1 bus has 64 pins just like the PC-XT and is combined with 40-pins on P2 for full AT-compatibility. The sum of the pins (64 +40 = 104) is the origin of the name PC/104.

PC/104-Plus

The original PC/104 bus has done a great job of supporting the 16-bit ISA standard. However, certain applications require greater throughput. Therefore, PC/104-Plus was defined and standardized. It is the 32-bit standard migrated from the desktop to the embedded world while still offering the same capabilities.

PC/104-Plus is a PCI implementation on a stackable board while maintaining the 3.6" x 3.8" form factor. PC/104-Plus modules can also include original PC/104 connectors to allow the most system configuration flexibility. PCI was chosen for a number of reasons. First it is the de facto standard for desktop 32-bit transfers that significantly improves throughput between cards. Next PCI is a known and proven standard. It is an open architecture that is well documented with no licensing requirements. Finally, PCI is supported by current and next generation integrated circuits. Even FPGAs have the PCI interface available to license as Intellectual property for custom designs.

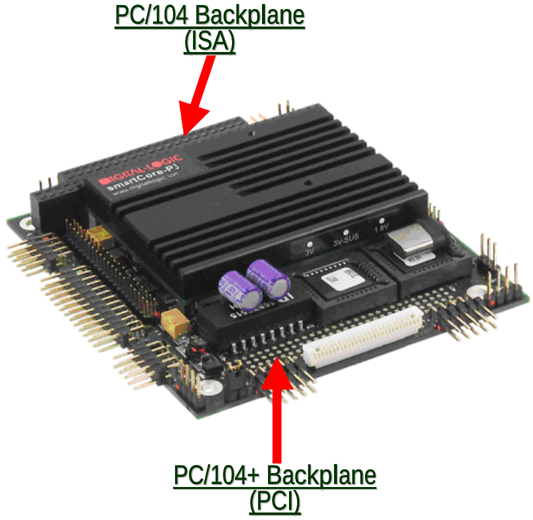
The key to success of the PC/104-Plus again lies in the connector scheme. A third connector is added opposite the PC/104 P1 and P2 connectors. It is a 4 x 30 (120-pin) 2-mm pitch stackthrough connector (as opposed to the 124-pin card edge connector on a standard 32-bit PCI card). A shroud covers the male pins of the connector and guides it to the next connector in the stack. The PC/104-Plus connector fits between the mounting holes. Spacing of the stacked modules is maintained at 0.6 inches.

Actual data throughput for the PCI bus is at least an order of magnitude greater than the ISA bus.

3.5.6 UDAS System Processor

ADL PIII MSMP3/SEV

- 700 MHz CPU (1.2-2.4 GHz early CY 04)
- Power management
- 256 Mbytes RAM
- 3 video input channels
- 100 Base-T Ethernet
- 2 USB Ports (supports hard drives)
- 2 Serial Ports (RS-232 or RS-422)
- PC/104+ (ISA and PCI backplanes)
- IDE bus for hard drives
- -32C to +71C – tested to 95° C



3.5.7 System Memory

UDAS System Memory is a 2-Gigabyte hard drive packaged as a Type II PCMCIA card. The PCMCIA card is will contain the necessary configuration files to identify the type of aircraft configuration that the UDAS is to initialize to.

The card is removed after flight as the method of data download, thus eliminating the need for serial download at the flightline.

The system memory has the following characteristics:

- Temperature Range – -40C to +85C
- Vibration – 15G peak to peak
- Shock – 1000G
- Altitude – 80,000 ft.
- Reliability – >1,000,000 hrs
- Capacity – 2GBytes

3.5.8 Data Download

Download of data from UDAS to ground systems for processing can be accomplished in many ways, using either wireless, wired, or removable memory. For the F-16 application, a PCMCIA card is being used such that the card can be quickly removed from the system, and a new card inserted. Two USB ports and 100 Base-T Ethernet are also available

Most notably, however, is the capability to wirelessly transmit data, saving time, and manhours for download.

3.5.9 UDAS Operating Software

Of most significance is that the UDAS Operating Software is focused on giving the Air Force total control over and flexibility in the data collected by UDAS, both near term, as well as long-term, as new UDAS versions and upgrades are implemented.

Control over data means that new functionality and data analysis routines, even ad hoc data analysis can be quickly and easily accomplished without overall changes to the operating software.

UDAS operates on the Linux Operating System using Red Hat 7.3, a Linux Distribution. Red Hat 7.3 is a stable, up-to-date Linux distribution, and provides a starting point for UDAS. Once UDAS is configured, there is no reliance on Red Hat except for discretionary updates and patches.

The primary application software is an embedded version of the PASS 3200 product by SBS technologies.

The UDAS application program consists of:

- The Device Layer code for all supported devices
- The Embedded PASS data acquisition system
- The Crash Survivable Memory (CSM) application
- The Maintainer Archive (MA) application
- PASS-3200 configuration file generator and analysis package

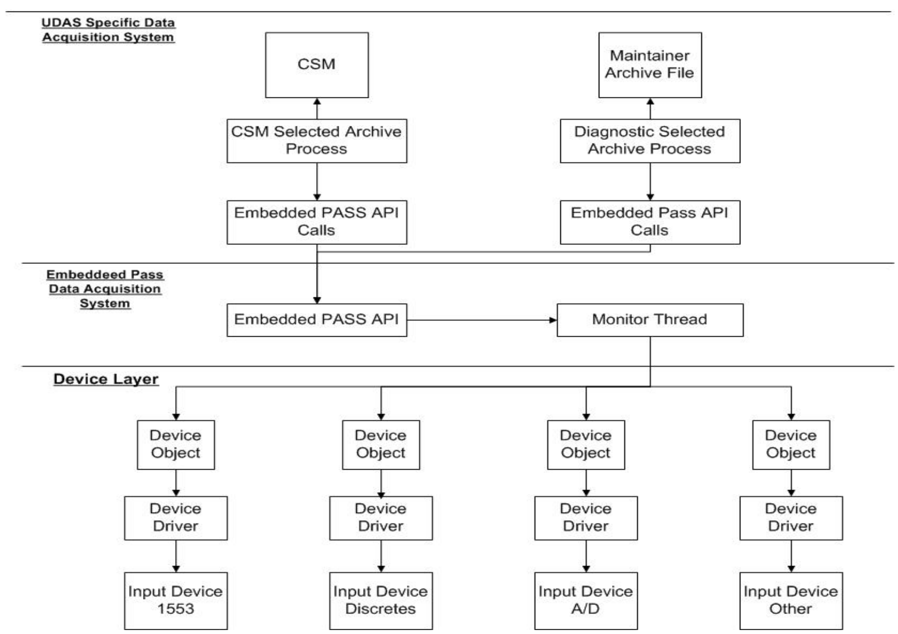
The Device layer is composed of a library of Linux device drivers and Embedded PASS device objects. The drivers provide low level initialization, test and data access device calls for each supported data acquisition device.

The Embedded PASS device object provides a common device interface to the Embedded PASS data acquisition system for each driver. The individual device objects are based on C++ inheritance classes with base classes defined for each general category of input devices (1553, A to D, Discrete). This two-level approach allows for easy addition of new input devices. Device drivers and device support object code for all supported devices will be included in the UDAS CDAP.

Embedded PASS Data Acquisition System has been ported to Linux from proven PASS-3200 data acquisition library, and provides two main components:

- A continuously running monitor thread to extract binary data
    - Monitor thread collects data on a timed or interrupt basis, based on individual device
    - Data is made available in a current value table and a FIFO queue
    - Current value table is used for data that is monitored periodically
    - FIFO is used for data, such as event data, that needs to be monitored continuously
    - Thread status on power up, initializes all data acquisition devices, and checks device status
    - Device failures reported to a UDAS specific Syslog file

    - Thread monitors all errors reported in Syslog file and reports errors via system status RT-SA on 1553 bus
- An Applications Programming Interface (API) that allows using applications to request, collect, and monitor extracted data
    - Designed to allow multiple outside applications to request collection of specific binary data from the monitor thread
    - Provides functions to read unique configuration files
    - Provides functions to request the collection of specific data by the monitor thread
    - Provides functions to retrieve data from the monitor thread FIFO or current value table
    - Provides functions to retrieve and apply conversion information for each data point



The UDAS CDAP CSM Software module is loaded at power-up, and configured at runtime from unique configuration files. The configuration file identifies the data source, extraction and conversion information, sampling specifications (time, flight state), event specification, and reports any CSM errors in UDAS specific Linux Syslog. The software module builds circular queue in CSM for periodic data and builds array of event data. All data consists of a timestamp, converted data. Data display and analysis is available post-flight using PASS ground stations and provided extraction utility.

The UDAS Maintainer Module is loaded at power-up and configured at runtime from unique configuration files. The configuration files identify data source, extraction and conversion information, sampling specifications, and event specification. The Maintainer Module builds the Maintainer Archive file containing large circular queue of periodic data, array of event data. This data is all time-stamped, converted data and also includes reports of any errors via UDAS Syslog file. The data is available during flight for download or display. Data display and analysis is also available post-flight using ground stations or provided extraction utility.

3.5.10 UDAS Enclosure Design Concept

The UDAS has a flexible enclosure design concept that allows the enclosure to be easily adapted to the aircraft dimension and interface requirements.

The enclosure design concept allows UDAS to match aircraft form factor, mounting, and cabling using multiple PC/104 enclosure types that are available on commercial market.

For the F-16 UDAS application, individual frames have been selected.

The enclosure fits in current CSFDR SAU space with current ATR mounting, connectors to mate with current aircraft cables, considering both connector type and cable lengths.

- EMI Filtered pins in connectors (-90dB at 700 MHz)

Enclosure machined from 6061-T651 plate aluminum

- Eliminates warping after milling
- Stainless steel guide bushings between frames

Vertical cooling fins exterior and interior

- CPU against the top for additional heat transfer

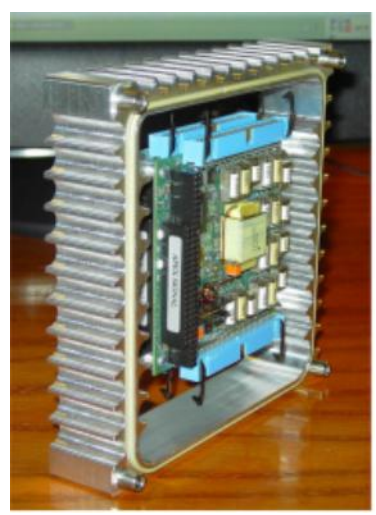
EMI gaskets of silver-plated aluminum in florosilicone binder

- High corrosion resistance
- 100 dB down at 500 MHz
- Meets all requirements of MIL-G-83528 type D

30-PSI differential pressure capability

PC card removable through door in bottom of enclosure

- Door opens to right to clear cables
- Includes EMI gasketing



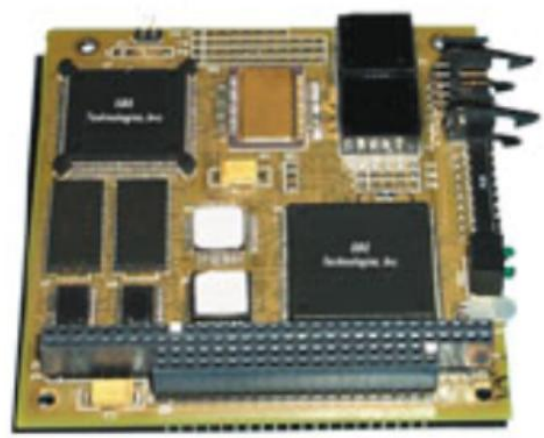
3.5.11 UDAS Capacity

The following capacity is being designed into the F-16 application of UDAS. Other applications may require different configuration based on aircraft profile.

MIL-STD-1553 - AMUX

SBS PASS PC/104-XT

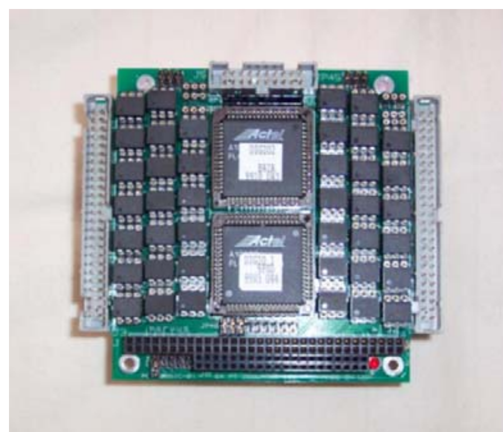
- Single channel dual redundant 1553 for AMUX
- Two/four channel cards available for additional multiplex bus interfaces
- Full function – BC, RT, BM
- 128 Kbytes dual port RAM
- Power-up self test
- BIT-RAM and Encoder/Decoder test
- -40C to +85C
- 31 RTs and all subaddresses supported



28 VDC Discrete – 28

Parvus 62 Point Digital I/O

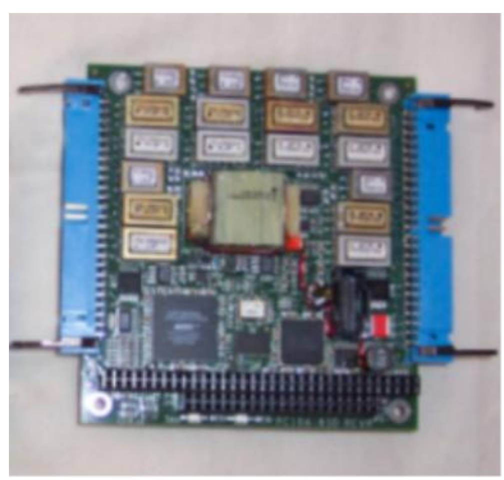
- 40 points of configurable I/0
- Opto-isolated to prevent feedback
- 16 additional logic level I/O
- -40C to +85C
- 8 address internal register



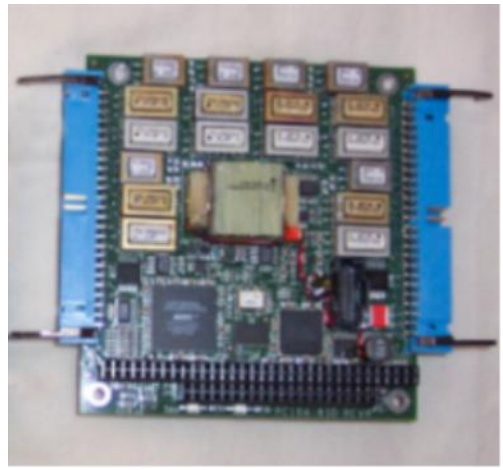
Transducer - LVDT – 5

North Atlantic PC104 73LD3

- 6 channels LVDT
- 16-bit resolution
- Transformer isolated
- Individual excitation inputs
- -40C to +80C
- Continuous self-test



Transducer - Synchronous – 2



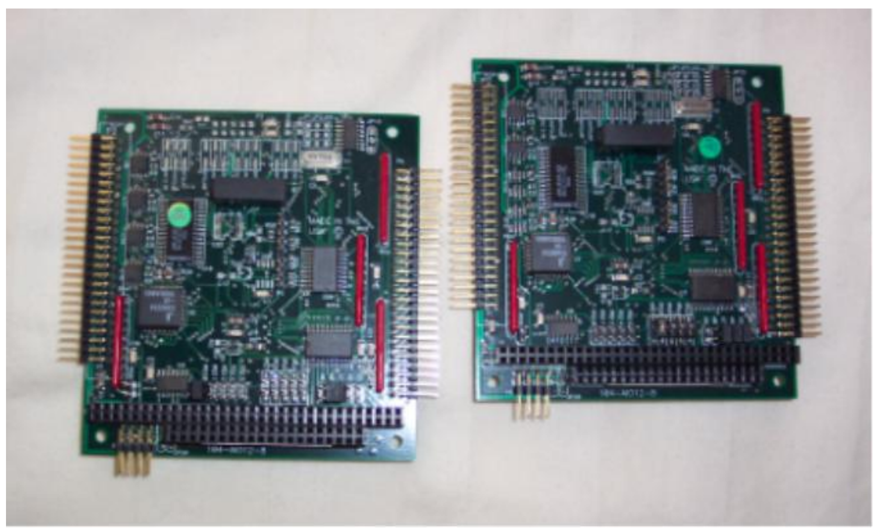
North Atlantic PC104 73SD3

- 6 channels programmable Synchro
- 16-bit resolution
- Transformer isolated
- -40C to +80C
- Continuous self-test

Analog–15 / Discrete (shunts)–17

Access 104-AIO12-8 x 2

- Analog I/O
  - 8 channels
  - Single ended or true differential
  - 100 KHz sampling rate
  - Programmable gain and range
- Digital I/O
  - 24 parallel bits
  - I/O pulled up to 5V
- Event counter/timer
- Frequency and pulse measurement
- 100 KHz sampling rate
- -40C to +85C



Crash Survivable Memory

The Crash Survivable Memory device in UDAS is provided by L-3 Communications Corp, and is the latest of the state-of-the-art for crash survivable memory. The unit is identical to the unit being developed for the JAS 30 Gripen fighter.

L-3 Communications/ Electrodynamics (L-3/EDI) manufactures a wide range of solid-state flight data recorders and crash survivable memory units for tactical military aircraft. They also design and manufacture solid-state data storage systems for military and aerospace applications. The company's expertise is in the design, development, and production of the data recorders, crash memory units, and data storage systems. These systems have been used on a wide range of platforms including B-1B, F-22, T-45, B-2, F-4, F-15, F-16, C-5 Galaxy, NATO AWACS, and the Space Shuttle.

The unit being used for UDAS has the following features:

- Based on qualified B-2.
- 4.5” wide, by 3” high, by 6” long (w/beacon) and weighs about 6.5 pounds.
- Cooled by convection and radiation.
- .5MB Memory expandable to 256MB.
- RS 422 data link. Can be adapted to 1553, Ethernet, IEEE 1394A/B or other high speed busses.

Survivability Features

- Hi-Level Impact Shock - 3,400g, 5-8 ms.
- Penetration - 6axes @ 500 lbs., 10 ft., 1/4” steel dowel penetrator pin.
- Static Crush - 5,000 lbs., 5 min. each axis.
- Fire Resistance - 1,000ºC *for 30 to 60 minutes*, *slow burn for 10 hours.*
- Sea Water Immersion to *20,000ft. for 30 days*.

3.5.12 UDAS Development Team

ET R-NET ENGINEERING & TECHNOLOGY LTD

- *Advanced Design Concepts; Lead UDAS System Design, Open Architecture*

L3 communications

- *Proven Crash Survivable Module technology; Most advanced CSM Module available today; Selected for Gripen, JSF*

SBS Technologies, Inc.

- **State of the art data collection software and 1553 bus analyzer**

RLW INC. EMBEDDED SOFTWARE

- *Industry leader in Wireless technology and embedded software design*

3.6 Application of Prognostics Framework to Monitor Aircraft Conditions & Trigger Events

It became clear, at the UDAS Preliminary Design Review (PDR) that the R-Net software approach does not include the extensive coding required to monitor aircraft parameters, per the F-16 specification, and trigger snapshot events. This is a critical part of the UDAS functions. However, the typical approach to hardcoding this functionality is indeed a huge effort. In order to ensure the success of the UDAS program, Giordano Automation has recommended that R-Net look at Giordano Automation's object oriented modeling approach to this issue. The result is a white paper, below, on R-Net's findings.

As a result, Giordano Automation's Prognostics Framework was used to monitor aircraft conditions and trigger events to create special log files. Section 3.6.1 provides a description of that application.

3.6.1 Use of Giordano Diagnostician in UDAS

Background

The UDAS system is divided into two modules, a common module that would be used on all aircraft applications (Common Data Acquisition Module - CDAM) and a unique module that provides interface for CDAM with the host aircraft (Aircraft Interface Module – AIM). The AIM module includes Configuration Files that configure CDAM and other software modules that provide application programs that to address specific data handling requirements of the host aircraft.

One of the attributes of UDAS is the capability to host third party programs. This capability includes functions that allow the third party program to access data that has been received by UDAS and to store results of data analysis in UDAS memory locations. These third party programs can be part of the common (CDAM) module or part of the host aircraft interface (AIM) software. If the third party program is part of CDAM it would normally be a general use algorithm whose parameters would probably be programmed by the AIM.

If the third party software is part of AIM software it would be installed in the CDAM third party program area when AIM is loaded at boot-up. In this case the program would normally be configured to fit the host aircraft needs during AIM development.

The UDAS concept anticipates, and the UDAS contract requires, that the UDAS software be non-proprietary and that it can be replicated or modified as needed by the government. That is a requirement for the CDAM common software and this requirement is expected to be maintained by the USAF UDAS program management. However, since the UDAS software provides a platform for third party software and allow it to be changed at will by the host aircraft program manager, it is reasonable that host aircraft management might elect to use some proprietary software if that arrangement was advantageous. Use of proprietary software in AIM would be transparent to the UDAS system since the AIM software can be changed as needed without necessitating a change to CDAM software.

UDAS F-16 Application

There is an F-16 requirement that UDAS create data records relating to special events. The record can be a time span of single or multiple data streams or a snap shot of multiple data streams at a

specific time. The F-16 UDAS Subsystem Specification and the subsequent F-16 Aircraft AIM Specification define the specific records that are required for the F-16 platform.

F-16 data is categorized into five data types:

Data Stored in the CSM

- Type 1 – Mishap data. This data is stored in the CSM and has the highest priority for recording. Records that must be stored in the CSM will be handled by UDAS mishap data processing software. This software cannot be changed without coordination of multiple USAF agencies.

Data Stored in UDAS Non-Volatile Memory

- Type 2 – Individual aircraft Tracking Data (IAT).
- Type 3 – Loads/Environment Spectra Survey Data (L/ESS).
- Type 4 – Engine Usage Data.
- Type 5 – Avionics Health Diagnostic Data.

UDAS is being designed to maximize the data handling processes in the CDAM and thereby minimize the software needed in the AIM. SBS has recommended, and the Software Team accepted, the concept that the CDAM software should include a set of programmable data handling rules that can be called by the AIM. The objective is the AIM Configuration Files simply call a specific rule and specify the parameters to implement the rule. For instance a rule might be to record the value of a certain data stream only when the data changes by some amount. The configuration file would call that applicable rule and specify the amount of change that would cause a new data value to be recorded. The rule would include the parameters for creating event records.

A configuration file might have ASCI values such for such a rule might be:

Rule Value = 3 (the rule for records)
Event = 112, Yes (data stream 112, when the discrete is yes create the record)
Data = 3,6,9,54, 115, 209 (the data streams to place in the record)
Time = current time- 300 (the base time is the 300 ms prior to the current time)
Range = -15,+15 (record the data for the selected data streams for the period +/- 15 seconds from the base time)
Store = xxxxxx (the memory location to store the record)

NOTE: if the change simple requires that the change be recorded the record portion of the rule will have null values

That generic data handling rules feature of UDAS would apply to the F-16 Type 2-5 data processing. However, to create a complete set of data handling rules we would need to have detailed knowledge of data handling rules for multiple aircraft. Creating generic data handling rules that are robust also requires more time and testing than available in the UDAS Advanced Development Model (ADM) program. Due to the limitations associated with an ADM program we have been planning to hard code the rules for F-16 in order to have an operative system to demonstrate the UDAS concept. Incorporation of the Giordano diagnostics software "Diagnostician" may offer the opportunity to delete the need to write hard code for the F-16 application AND would provide a demonstration of the use of third party software for diagnostics and prognostics data analysis.
In the UDAS Program, there has been much discussion about data analysis capability in UDAS, but a demonstration would go a long way toward convincing people that UDAS can actually include that capability. It should be noted that the on-board data analysis function must not interfere with the basic data acquisition and mishap data handling functions otherwise there could be lost of data and delay of mishap data storage in the CSM beyond the required time frame. For

any data analysis or other third party software to be incorporated, CDAM software must include a priority system of interrupts to assure that data acquisition and the mishap data processing and storage functions have CPU priority. Some delay of data analysis is not a major problem since the results of data analysis is not part of a control system and near real time for data analysis is good enough.

Use of Giordano Diagnostician

We understand that the Giordano Diagnostician includes record creation capability among the Diagnostician functions. We propose that Giordano and the UDAS team explore the use of Diagnostician as a third party program to fulfill the requirement for creating Types 2-5 records for the F-16 application. Other Diagnostician capability should also be considered and implemented as feasible. Using the Diagnostician would significantly help shortened the UDAS schedule and would demonstrate how UDAS can use third party programs within the UDAS in-flight diagnostic/prognostic data analysis functionality. Preliminary discussions have indicated use of Diagnostician may be feasible.

R-Net has done a preliminary review of use of Diagnostician. We would like to start a dialog with Giordano to get a better understanding of the program and to determine if use of Diagnostician in the ADM system is truly feasible. If it is, we would then develop a set of actions to implement some portion of Diagnostician in the ADM system. There are a number of issues that we have identified that would have to be resolved, but they do not appear to be too difficult. One of them is that Diagnostician would have to be ported to Linux. I believe that making Diagnostician part of the F-16 AIM as a designated AIM data analysis program is the best way to proceed as discussed above.

3.6.2 Prognostics Framework Application to F-16 UDAS AIM

The Prognostics Framework is an enhancement of Giordano Automation's Diagnostician. The Prognostics Framework extends the Diagnostician to predictive reasoning. In run-time, the Prognostic Framework reads operational data, test and sensor results and provides a call-out of existing faults or impending failure events. It does this by correlating test /sensor results, under expected/defined operating conditions, to a hierarchical model of the system. The model can be derived directly from CAD data (EDIF netlists) or by building a hierarchical model of the system using the development system. The user identifies what test and sensor data will be available in run-time, and the coverage of those tests/sensors across the design. Additionally, the user can identify and define detailed algorithms and mathematical functions to be applied to the data, as well as filters. Run-time reasoning is based upon the coverage defined for the tests/sensors. Set covering algorithms, pre-computed into the run-time knowledge base, are used to increase monitoring and diagnostic accuracy and speed.

What Does the Prognostics Framework DO?

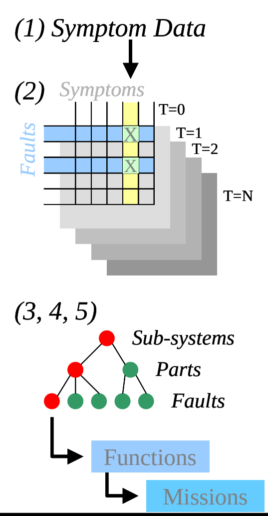
- Integrates Diagnostic / Prognostic Mechanism Outputs From Many Subsystems
- Provides Prognostics Analysis / Reasoning
  - Monitors Degradation of Signals / Measurements over time
  - Depletion of Consumable Items
  - Accumulates Wear Factors
  - Engineering Correlations
  - Tracks PMS based on Wear / Use factors as well as time
  - Serial Number Tracking of high-end components
- Allows for integration of complex algorithms and functions
- Provides Diagnostic / Prognostics Analyses / Reasoning
- Let's you look at trend data
- Links to Tech manuals, PMCS, Supply, etc., based on specific fault or equipment condition

The Prognostics Framework contains many features and advanced mathematical and function processing that allows it to look forward in time. It can monitor the depletion of consumables, the degradation of various parameters alone or in combination with other parameters. It can also monitor, assess and predict remaining life of various types of system elements. Additionally, the Prognostic Framework is capable of integrating other prognostic techniques that are highly specific to various items into the overall framework, such as oil monitoring systems, vibration analysis systems, thermographic/video imaging, etc. Integration of prognostic techniques into the Prognostics Framework is accomplished by defining the processed results of those techniques as one (or several) test/sensor inputs to the model, including fault/symptom coverage and critical impact on functions. If the prognostic technique has its own interface, that interface can be displayed by the Prognostics Framework run-time user interface at any time. However, the prognostic technique interface is usually only displayed by the Prognostics Framework run-time user interface when the prognostic technique indicates a symptom or an `impending failure.`

The intent behind the Prognostics Framework is first, to leverage off existing system diagnostic, (test and sensor) resources to achieve condition monitoring and prognostics. Secondly, it is to provide an open architecture information framework under which any equipment-specific prognostic and trending technique can be integrated into an overall system-level health management system. The health management system includes information on the status of individual systems and equipment contained in a hierarchical representation of the system. The health management system also gives an indication of the system's overall mission capability and readiness to perform a mission across specific timeframes. It does this based on the correlation of equipment to functions, and the assigning of equipment faults to the ability of the equipment to perform the function, and then correlating functions to mission capability. Finally, the information framework includes repair item data and repair action data fields that enable integration of maintenance / logistics data directly within the model, or

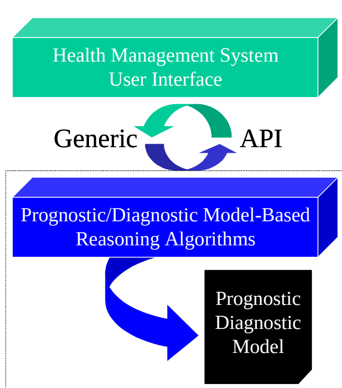
How does the Prognostics Framework reason?

1. **Accept prognostic/diagnostic software outputs, BIT and parametric data as *symptoms***
2. **Apply model-based reasoning AI algorithms to prognose/diagnose the implication of out of tolerance *symptoms* on each future time point defined in the model**
3. **Identify the components and sub-systems affected by predicted failures - *sub-system health***
4. **Identify the functions and missions affected by predicted failures - *mission readiness***
5. **Identify the repair actions needed - *anticipatory maintenance***



ON-BOARD HEALTH MANAGEMENT SYSTEM

- Run-Time Software designed for embedded applications
- C Code that can be cross-compiled to any platform
- Implementation Strategy: Centralized, Distributed, Hierarchical
- Software functions serve as building blocks
  - Integrate building blocks to build desired functionality
  - Design User Interface as desired or use existing
  - Well-documented API



links to other systems, such as supply data base systems and interactive electronic technical manuals.

The information architecture used in the Prognostics Framework is powerful and flexible. Models for specific pieces of equipment can be combined into the overall system hierarchy and sensor implications and interdependencies across the system level can be defined.

For the UDAS system applied to the F-16 replacement of the F-16 CRFDR, the Prognostics Framework is used to preprocess and monitor all aircraft parameters recorded by the data acquisition system for specific trigger events. Upon triggering of an event, a specific log file entry is generated. The Prognostic Framework is applied to Types 2 (Aircraft Tracking), 3 (Structural Data) and 4 (Engine Monitoring) data.

F-16 Data Model

The F-16 model was set up to identify trigger events rather than faults. A different trigger event was defined for each different type of data to be stored. The events are used to capture snapshot data, details around specific events, occurrence counts and time spent in specific states as defined in the F-16 CSFDR specification.

Source Data Inputs

All data to be input to UDAS was identified as source data inputs. The definition of the data includes:

1. Input data name
2. Description (English language description plus reference paragraph from specification)
3. Data Type (Boolean Yes/No Value, Floating Point Number, Integer Value, or String)
4. Data Dimension (e.g., Discrete, Timestamp, Degrees, Knots, etc.)
5. Data Size (number of bits)
6. Data Location

Data Processing

The processing of the raw input data (source data inputs) to derive calculated parameters and for the evaluation of the inputs were identified in the Source Data Processing tool. This includes:

1. Mathematical equations to be applied to raw input data to generate calculated parameters
2. Functions/algorithms to be applied to raw input data to generate calculated parameters
3. Filtering to be applied to raw or calculated parameters (primarily used here for definition of valid ranges)

Prediction Model

The Prediction Model was used to correlate raw and derived (calculated) parameters to criteria causing an event to be triggered.

3.6.2 Simple Example

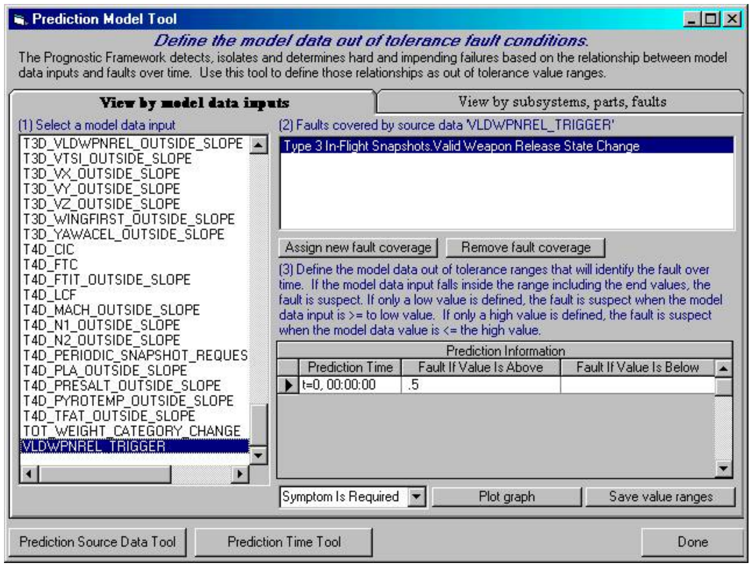
The following is provided as a simple example of the application of the Prognostics Framework to the F-16 UDAS to cause the triggering of an event to be logged. Most of the modeling is actually much more complicated due to the functions applied to monitor events, such as the analysis for Out of Slope and the Peak/Valley search algorithm.

<u>Requirement:</u> Trigger an Event upon Valid Weapons Release

<u>Event Name:</u>
Type3 In-Flight Snapshots.Valid Weapons Release State Change

Where [Type3 In-Flight Snapshots] is the category, and [Valid Weapons Release State Change] is the actual trigger event.

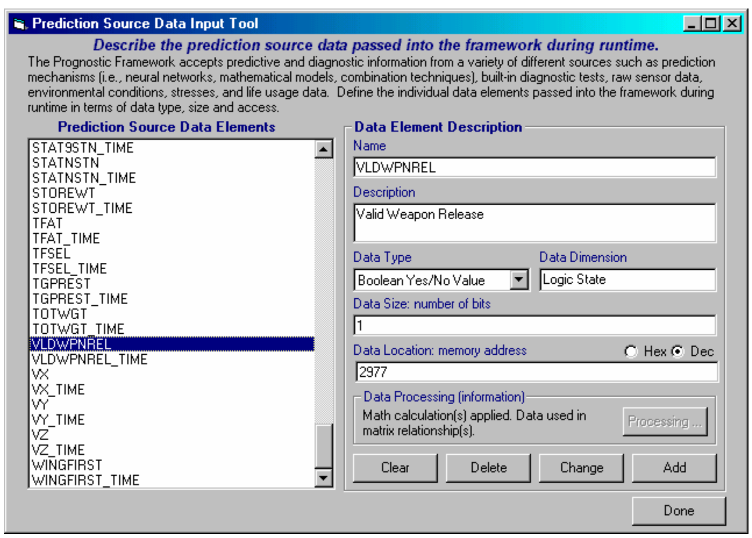
<u>Event Trigger Name:</u>
VLDWPNREL_TRIGGER



<u>Related Source Data:</u>

Name: VLDWPNREL
Description: Valid Weapon Release
Type: Boolean
Dimension: Logic State
Size: 1

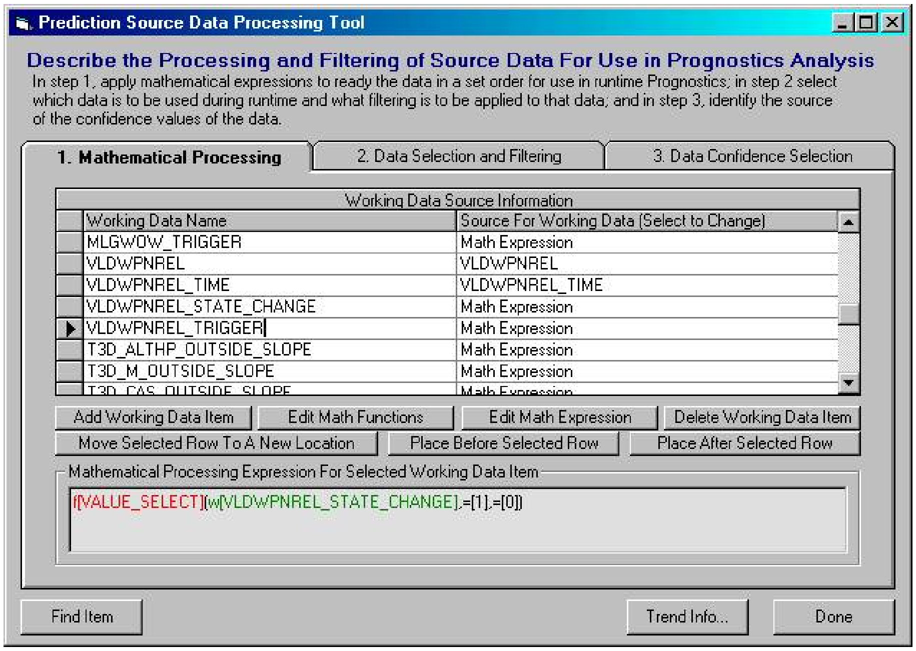
Name: VLDWPNREL_TIME
Description: Valid Weapon Release – time reference
Type: Floating Point Number
Dimension: Time Expression
Size: 64



Processed (Derived) Data

Working Data Name	Equation or Function	Model Data Name
PREV_VLDWPNREL	w[VLDWPNREL]	
VLDWPNREL_STATE_CHANGE	s[VLDWPNREL]-w[PREV_VLDWPNREL]	
VLDWPNREL_TRIGGER	f[VALUE_SELECT](w[VLDWPNREL_STATE_CHANGE],=[1],=[0])	VLDWPNREL_TRIGGER

Filter: None

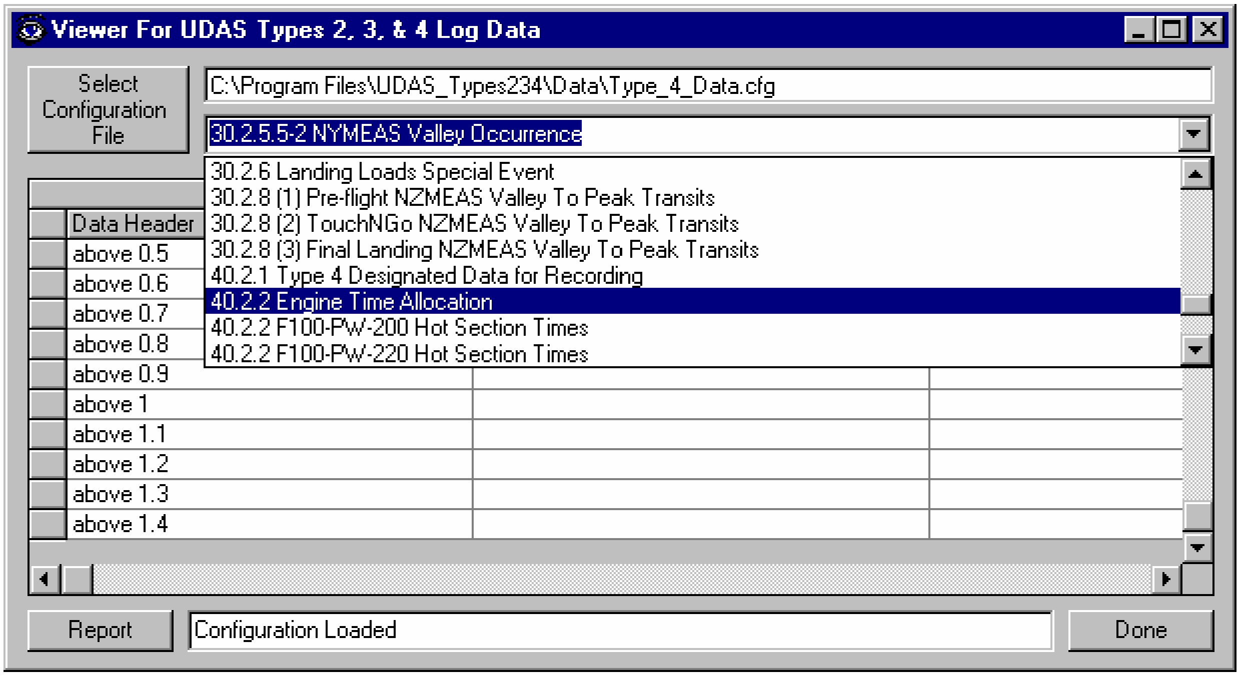


Since the Prognostics Framework generates numerous reports, the resulting modeling details and algorithms are self-documenting.

A configuration file is used to define the requirements for the creation of specific log files to be created. Additional log files, or modifications to existing log files can be accomplished by adding entries in the configuration file.

Log File Viewer

A viewer was created to support the integration and test process. The viewer enables the user to select a log file created from a flight operation or test run, and view its contents. The viewer is shown below.



The following figure is an example of a view for a Log File created for Type 4 data, Engine Hot Section Times, where the time that the engine is at various temperature ranges is accumulated and presented.